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On the performance of micro injection moulding process simulations of TPE micro rings

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Abstract

Micro injection moulding (µIM) process simulations can be used as powerful tool for the optimization of the design of mould, part and process. However, numerous scale effects introduce relevant challenges in terms of both validation and accuracy of the simulations [1-2]. In this research, a case study based on µIM of thermoplastic elastomer (TPE) micro rings for sensor applications was treated. Injection moulding process simulations using Autodesk Moldflow Insight 2016® were applied with two main tasks: the first was the prediction of main parts defects. The second was the forecasting of the effects of the main injection moulding process parameters on the part geometrical accuracy. A 3D multi-scale mesh was used. The outcomes of the simulations were compared to real moulded parts based on SEM inspections and focus variation measurements. The results show that the model was capable of accurately capturing the position of the micro ring weld lines and air traps. Process simulations also correctly predicted the effects of the investigated process parameters on the part dimensions. The average deviation between real parts measurements and simulations results was 2 µm, demonstrating that single digit micrometric simulation accuracy was successfully achieved.

Case study

- Objective ⇒ apply µIM process simulations as a tool for product/process optimization, leading to consistent reduction of experimental and metrological efforts
- Volume = 1.5 mm^3; mass = 2.2 mg

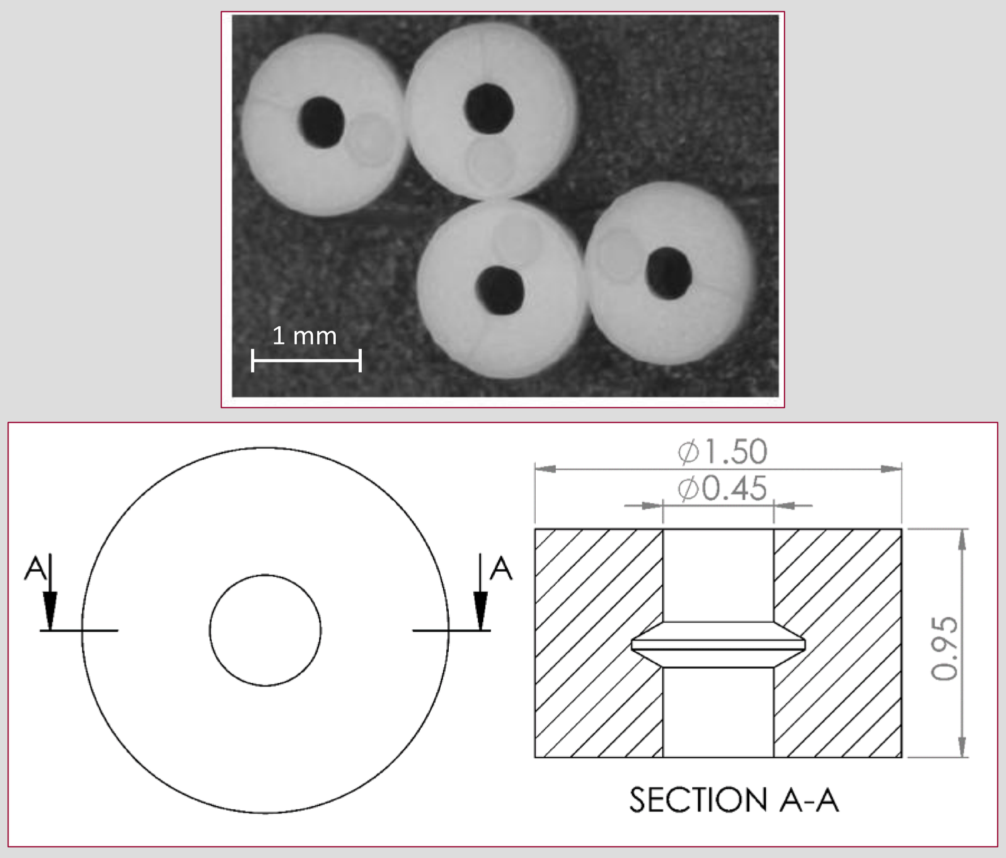

Fig. 1. Appearance (top) and geometry with nominal dimensions in mm (bottom) of the micro rings

Experimental setup

- The effects of 4 process parameters on the outer diameter (OD) of the rings were investigated
- µIM machine: Wittmann-Battenfeld MicroPower 15
- Material: Styrene-ethylene-butylene-styrene (SEBS)
- 4-cavity mould
- Design of experiment (DOE):
  - General full factorial design (Table 1) with five repetitions
- Measurements of OD performed with a focus variation optical microscope:
  - Magnification: 5×
  - Lateral resolution: 1.75 µm
  - Expanded uncertainty (ISO 15530-3): 2.0 µm

Process parameter	Experimental levels
Melt temperature [°C], T_{melt}	210, 225
Mould temperature [°C], T_{mould}	30, 40
Holding pressure [bar], p_{hold}	300, 500, 700
Injection speed [mm/s], v_{inj}	50, 70 ,90

Table 1: Experimental micro moulding conditions

Simulation setup

- Autodesk Moldflow Inisght (ASMI) 2016® was used for the numerical analysis
- The model comprised parts and feed system (Fig. 2)
- A multi-scale 3D mesh was applied:
  - 500 µm element size on the sprue
  - 50 µm element size on the micro rings
  - Total of 1.4 ·10^6 tetrahedrons
- Mathematical models:
  - Flow ⇒ 3D Navier-Stokes equations
  - Rheology ⇒ Cross-WLF model
  - Thermodynamics ⇒ Tait model

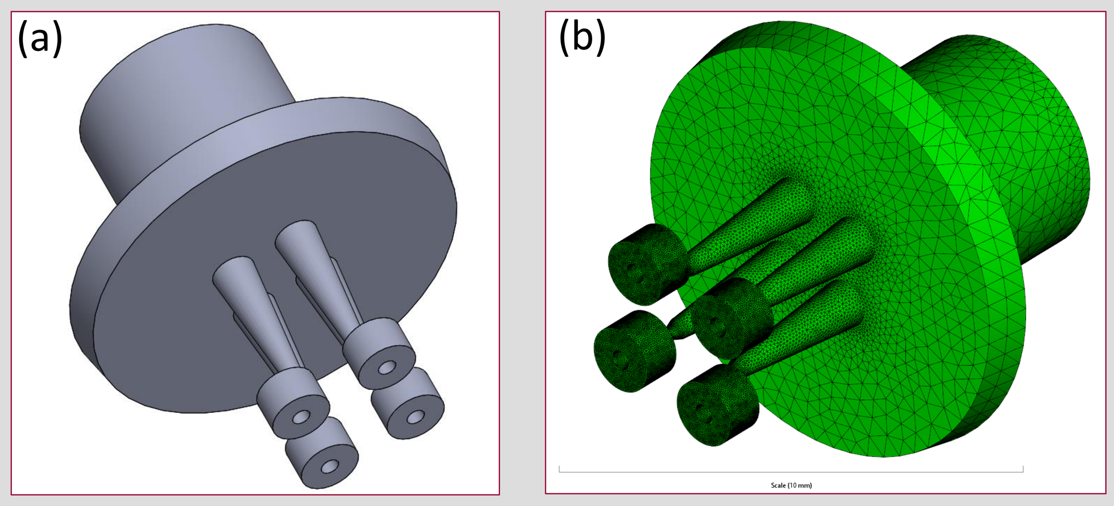

Fig. 2. CAD model (a) and meshed model (b) of the parts with feed system

Results

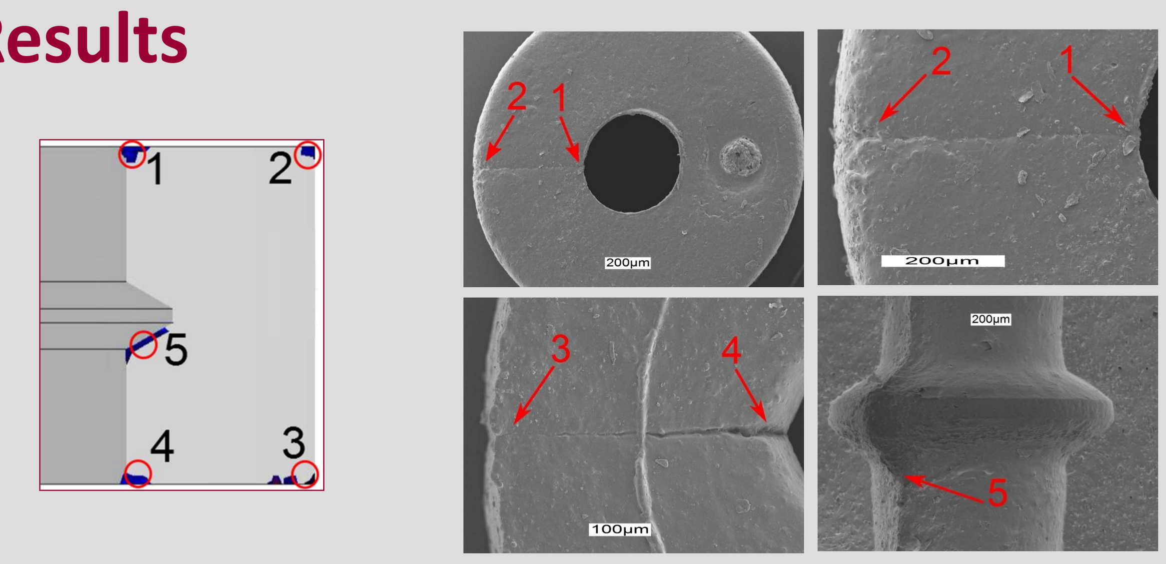

Fig. 3. Predicted air traps (left) and real defects (right)

- The presence and position of air traps, caused by the asymmetric gating, were accurately predicted by the numerical model
- Weld line position was also well forecasted by the simulation results

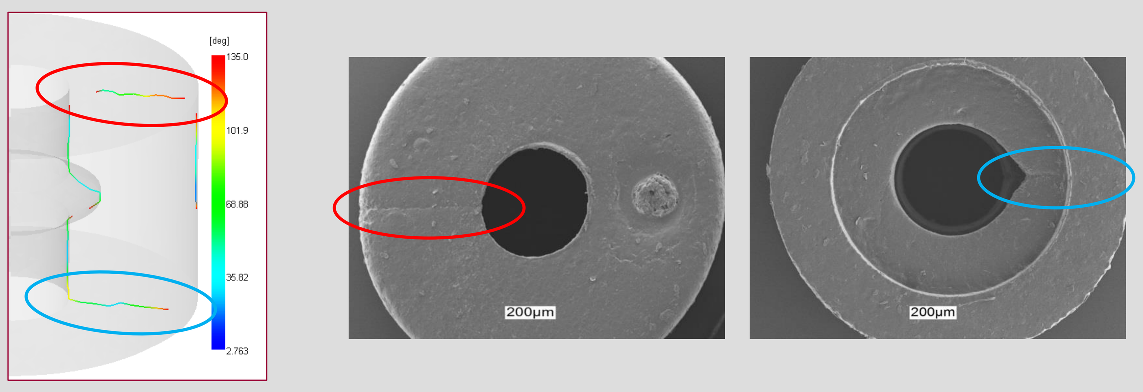

Fig. 4. Predicted weld lines (left) and real defects (right)

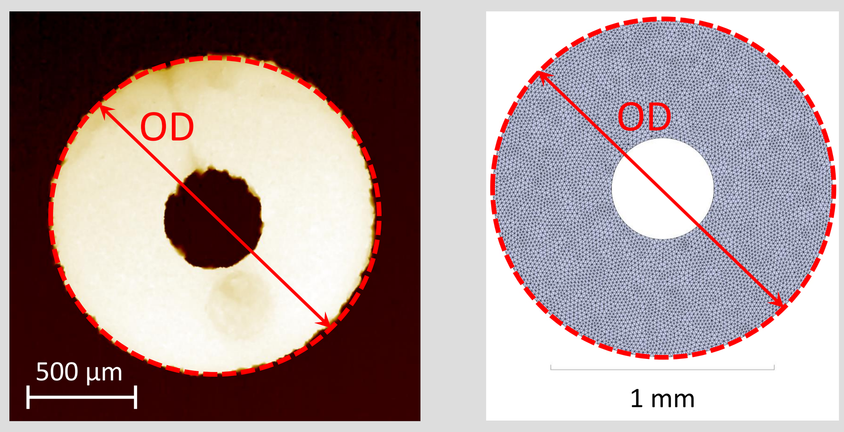

Fig. 5. OD measured (left) and simulated (right)

- Average deviation between experimental and numerical OD results was 1.6 µm
- The effects of the 4 process parameters were the same for real measurements and numerical results (i.e. slopes had the same sign) in all the investigated ranges

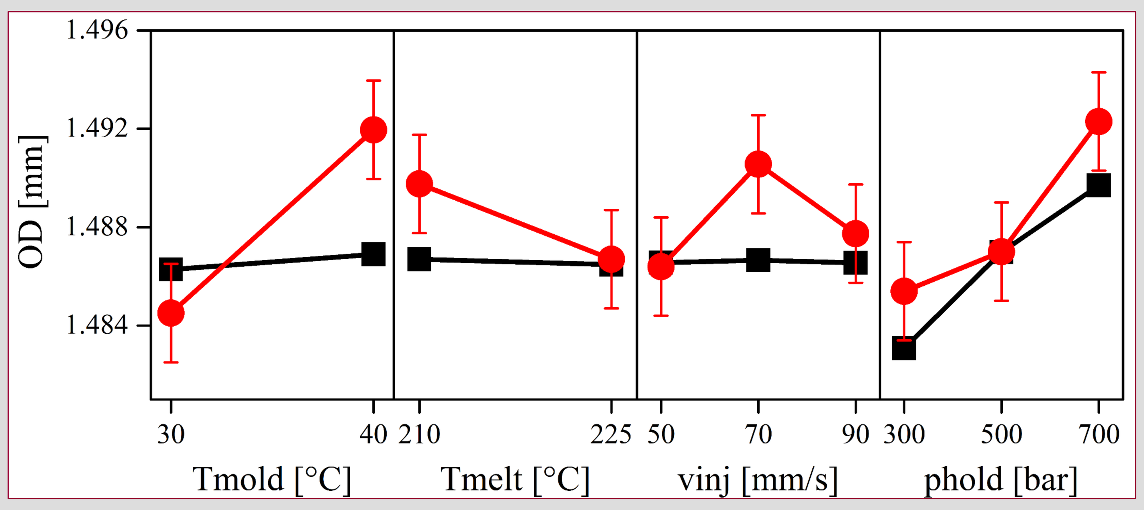

Fig. 6. Main effects plot of OD as measured (red) and simulated (black)

Conclusion

Simulations results showed very high accuracy. An average deviation of 1.6 µm was observed between real measurements and numerical results. Simulations were capable of accurately predicting the effects of the four process parameters. They were also capable to effectively predicting the position of the main defects affecting the micro rings quality.

µIM process simulations could be used as an effective tool for process and product optimization, leading to a consistent reduction of the experimental and metrological efforts needed to set up a production that is both defect-free and within tolerances.

References

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